U.S. ARMY ST 44-188-5G

AN/TPS-1G
MOVING TARGET INDICATOR SYSTEM

MILITANT

U.S. ARMY AIR DEFENSE SCHOOL

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CHAPTER 1

INTRODUCTION TO TEXT

1. PURPOSE AND SCOPE

a. Purpose. The purpose of this text is to provide technical information on the AN/TPS-1G radar set.

b. Scope. This text covers the theory of the moving target indicator system (MTI).

2. REFERENCES

The AN/TPS-1G troubleshooting manual is a basic reference for this text.

CHAPTER 2

PRINCIPLES AND FUNCTIONING OF MTI SYSTEMS

Section I. THEORY OF OPERATION

3. GENERAL

a. Normal operation. The AN/TPS-1G radar when operated in NORMAL, has at the indicating screens a display of all targets, both moving and fixed. Generally, radar data are desired only for moving targets and these data can be obtained by having a moving target indicator (MTI) operation, that cancels the fixed target returns within its circuits. The AN/TPS-1G radar employs a reference or coherent phase system. By having an MTI operation, the set is capable of presenting only moving objects with an approximate 95 percent cancellation of fixed targets from its indicating screens.

b. Gated MTI. By using gated MTI, only moving targets may be displayed for close-in ranges in clutter area; both fixed and moving objects can be displayed for ranges out in clutter-free areas. The loss of sensitivity in gated MTI operation is not greatly decreased from that of NORMAL operation.

c. Gated MTI circuits. The circuits to provide gated MTI are contained in the signal comparator shown in figure 1.

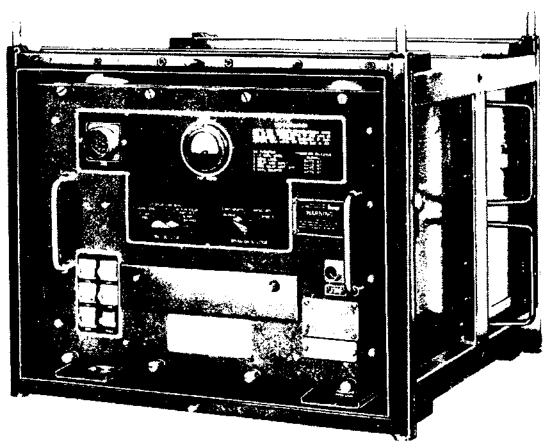

Figure 1. Signal comparator.

d. Basic MTI theory.

(1) In all radar systems the received rf signal voltage bears a definite phase relationship to the rf voltage of the corresponding transmitted signal. The phase depends

on the distance between the radar antenna and the target (fig 2). The upper diagram shows the echo returning in phase (0°) with the radio-frequency wave of transmitted pulse. The lower diagram shows the different phase that results when the echo returns from a slightly more distant target.

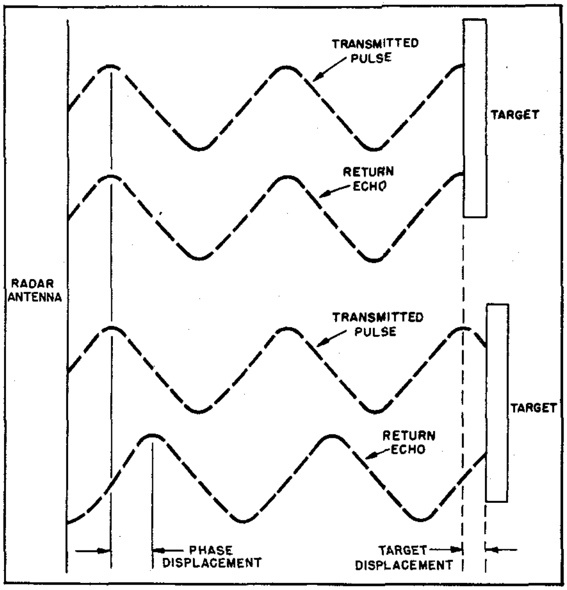

Figure 2. Phase relationship of transmitted signals versus echo signals.

(2) In general, when the radar antenna itself is fixed, fixed objects produce echoes with a fixed phase relationship from one receiving period to the next, whereas moving objects produce echoes with a different phase relationship from one receiving period to the next. It is by taking account of this difference in phase between successive receiving periods that the MTI circuits can discriminate between fixed and moving targets.

(3) The method used to derive MTI signal information for radar indicator presentation is:

(a) The echo signals are converted an conventional superheterodyne fashion to an intermediate frequency of 60 mc, after which they are amplified and then limited to remove amplitude variations.

(b) A 60-mc reference signal is generated by an oscillator and phase-locked to a sample of the transmitted radar pulse that has been converted to 60 mc by the same superheterodyne local oscillator used to convert the echo signals. The

reference signal generator, which is not to be confused with the superheterodyne local oscillator, is called the coherent oscillator or coho.

(c) Both the 60-mc echo signal and the 60-mc reference signal are applied to a phase detector which responds to the phase difference between the two signals applied to it.

(d) The phase detector produces a video pulse having the timing and duration of the 60-mc echo signal. The amplitude and polarity of the video signal is determined by the phase difference between the echo signal and the reference signal. Since both conversions to 60 mc are performed by the same local oscillator, the two 60-mc signals have the same phase difference as the two rf signals from which they were derived. Hence, the video output of the phase detector represents the phase difference between each transmitted radar signal and the corresponding radar echo.

(e) A 9-mc cw signal (carrier) is generated and the video signal resulting from the phase detection is used to amplitude-modulate it.

(f) The amplitude-modulated carrier is amplified and distributed to two channels called, respectively, the delayed channel and the nondelayed channel.

(g) The signal in the delayed channel is delayed for a period that is exactly equal to the time between radar pulses (approximately 2,500 μsec). The delay signal is then amplified and the video signal is recovered in an amplitude-modulation detector.

(h) The signal in the undelayed channel is amplified and detected in a similar manner. The undelayed channel has exactly the same overall gain and other electrical characteristics as the delayed channel, except that it introduces no delay.

(i) The delayed and undelayed video signals are combined in opposite polarity; i.e., subtracted one from the other. If the two signals are identical in amplitude, they cancel and no output results. If the two amplitudes are different, the difference is the output signal. It is important here to realize that the two signals being combined represent, respectively: (1) the radar echo received during the present pulse-repetition period, that travels via the undelayed channel; and (2) the echo received during the previous period, that travels via the delayed channel.

(j) The amplitude difference between the two video signals, which is itself a video signal, is amplified and applied to the A-scope and PPI screen for display.

(4) In analyzing this procedure, it can be seen that signals from fixed targets, which generally have an unchanging phase relationship to the transmitter pulse from one pulse period to the next, produce in the phase detector recurring video signals of the same amplitude and polarity. When one video pulse is combined with a preceding pulse of opposite polarity, the video signals cancel and no information is passed on to the radar indicators.

(5) Signals from moving targets, on the other hand, generally have a varying phase relationship to the transmitted pulse, with the result that signals from adjacent periods produce signals of different amplitudes in the phase detector. When such pulses are combined after passing the cancellation circuits, the difference in signal amplitudes provides a video signals, which is passed on to the PPI and A-scopes.

NOTE: The foregoing analysis applies to gated-MTI operation during that portion of the pulse-repetition period when the MTI circuits are active.

There is a condition where the MTI circuits do not produce moving target information. This condition occurs when the relative movement of a target is at a speed that produces a phase difference corresponding to an exact number of half wavelengths between pulses. In this case, although the object is moving, the phase difference between transmitted and received signals is fixed, and therefore, no signal will be produced for radar indicator displays. The only adverse effect is a tendency to lose objects that move a distance of an exact number of half wavelengths during the time between pulses. This occurs at certain definite relative speeds (blind speeds) determined mainly by the wavelength and pulse rate. Figure 3 shows how the video level (after passing through the cancellation circuits) varies for the relative speed of objects. However, moving targets traveling at blind speeds may still produce detectable signals. The signals result from varying-phase reflections such as those produced by a propeller.

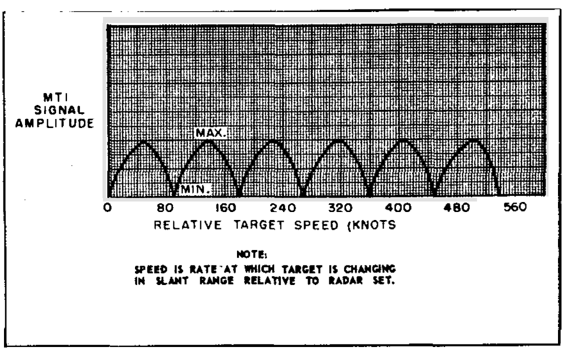

Figure 3. MTI signal amplitude versus relative target speed.

e. MTI circuit requirements.

The following circuit requirements are necessary to accomplish satisfactory MTI operation. These considerations are in addition to those required for normal radar reception:

(1) The pulse repetition rate or pulse timing must be exactly equal to the timing of the delay in the supersonic delay line and associated signal circuits. This is accomplished in the signal comparator by using the delay line not only for delaying signals but also for setting the pulse repetition period.

(2) The 60-mc reference signal must be synchronized with the phase of the transmitter signal. The coherent oscillator that develops the 60-mc signal is a stable 60-mc cw oscillator and is phase-locked by transmitter pulses received via the coho mixer.

(3) Amplitude variations of received signals should be minimized to afford maximum detection capability. The last three stages of the 60-mc if amplifier are designed to limit the amplitude of signals received from the receiver-transmitter preamplifier.

(4) The signal output levels of the delayed and undelayed signal circuits for cancellation of fixed targets must be maintained. An automatic gain control (AGC) circuit helps maintain the balance of the signal levels of the two circuits by controlling the gain of the amplifier in the delayed circuit.

(5) The overall transit time of the pulse timing circuits and of the delayed-signal circuits must be the same. A small fixed delay is added in the receiver-signal output circuit of the delayed amplifier, the amount of delay being sufficient to compensate for the longer transit time of the pulse-timing circuit.

(6) A means must be provided for conveniently adjusting the MTI circuits. A meter, a meter switch, and panel controls are included that provide a simple means of alining the circuits.

(7) Both the transmitter and local oscillator signals must be as free as possible from jitter and frequency and/or amplitude modulation. DC is used for the filament supplies of both magnetron and local oscillator tubes. Special consideration is given to the modulator pulse circuit to provide jitter-free operation.

(8) Arcing and magnetron frequency pulling in the rf transmission system must be kept at a minimum. This is partially accomplished by careful design of the rf transmission line system. (This design is determined by the nominal characteristics and power output of the transmitter magnetron.)

f. Operating limitations.

(1) A radar system without MTI generally has certain limitations in detecting objects.

(2) The vertical radiation pattern of the antenna generally contains several null points. The nulls are quite sharp but at long ranges a considerable area exists where aircraft may not be detected. The nulls are caused by ground reflections that cancel the free-space radiation in areas where the free-space radiation and the ground reflection are out of phase. Figure 4 shows an actual pattern of an experimental model of antenna AS-673/TPS-1E. The curve represents maximum ranges observed on a single-engine propeller-driven aircraft (AD-4N) flying over land.

(3) Also, with a radar system without MTI, objects could remain undetected due to an insufficient number of pulses striking the object. The ability of the eye to detect a target on the indicators is dependent on the number of pulses striking the target during the time the antenna is scanning it. The number of scans is dependent on

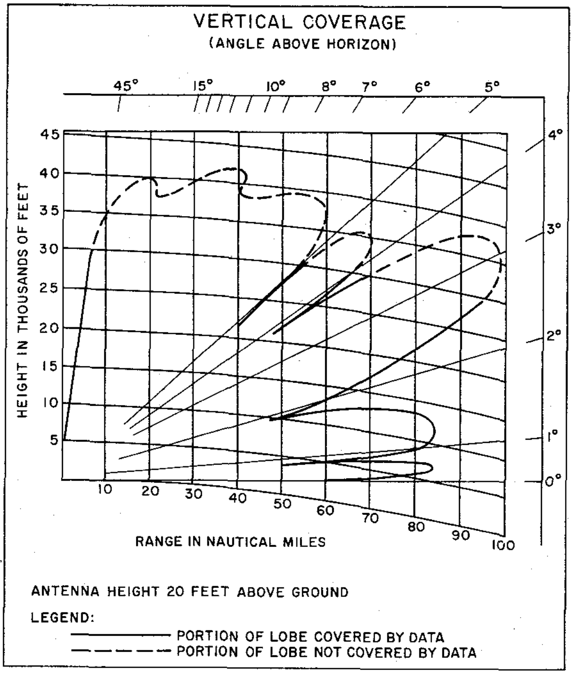

Figure 4. Vertical radiation pattern characteristics.

the pulse rate, antenna horizontal beamwidth, antenna rotation speed, and the speed and direction of the target. With the pulse rate and beamwidth fixed, the ability to detect an object is dependent entirely on antenna rotation speed and the movement of the target. In general, slower antenna rotation speeds increase the ability to detect weak targets.

(4) Another possibility, often overlooked, is that of losing a target in a blind area caused by an obstruction, such as a mountain or building, or in blind areas beyond the horizon. Obviously the altitude of a target determines to a great extent the likelihood of a target being lost in these blind areas. As the height of the target is not known, it is often difficult to determine whether or not target loss is due to its altitude.

(5) The ability of the MTI to detect moving targets and/or to differentiate between fixed and moving targets is dependent on a number of additional factors. If the moving target is in an area free of clutter (fixed targets), the main limiting factor is the optimum relative speed (89.4 knots and multiples thereof) of the target for the repetition rate and rf wavelength.

(6) Figure 3 shows this relationship of the amplitude of MTI video signals developed (before video limiting) versus the speed of the target. Blind spots appear at

relative speeds of 89.4 knots and integral multiples thereof. It should also be noted that maximum MTI video signals are developed at speeds of 44.7 knots removed from blind speeds. The values given are approximate for the wavelength (23 cm) of the transmitted signal at midband and at a pulse repetition rate of 440 pps.

(7) The first blind speed or velocity at which the resultant MTI video signal is zero, for other values of wavelength and pulse repetition rate, can be determined from the formula:

$$v = \frac{\lambda f \gamma}{102.9}$$

where:

v = lowest blind speed of the target in knots.

λ = wavelength of the transmitted signal in centimeters.

$f\gamma$ = pulse repetition rate in pulses per second.

(8) Other blind speeds occur at integral or whole multiples of the lowest blind speed (v).

(9) Velocities at which the resultant MTI video signal is maximum occur midway between the blind speeds. For example: If the lowest blind speed is 89.4 knots and the second blind speed is 178.8 knots, the MTI video signal will be maximum at 44.7 knots and again maximum at 134.1 knots.

(10) If the moving target is in a clutter (fixed-target) area, the ability to detect the target is dependent on several factors. Most of these factors have to do with the limitations of the MTI circuits in balancing out fixed-target signals. With the antenna at rest, the subclutter visibility (ability to detect moving targets in the presence of fixed targets) is limited at moving-target signal levels of not more than 26 db below that of clutter signals which are at or above the limit level of the 60-mc amplifier.

(11) Subclutter visibility, as far as the radar circuits are concerned, is mainly determined in most cases by the stability of the local oscillator. Stability is defined by the degree of local oscillator amplitude and/or frequency change from one receiving period to the next.

(12) One factor that seems to produce the greatest limitation on the ability to detect moving targets in the presence of fixed targets is the rotation of the antenna. As the antenna rotates, the amplitude and phase of clutter signals change according to shape of the antenna pattern and the rf phase distribution of the pattern. Even with slow antenna rotation, amplitude and phase changes of clutter signals can be sufficient to prevent complete cancellation of the clutter signals.

4. BASIC MTI BLOCK DIAGRAM

a. The block diagram of a simple or basic MTI system is shown in figure 5. It depicts the antenna, the radar transmitter, a coherent oscillator, a receiver, detector, and nondelay and delay channels.

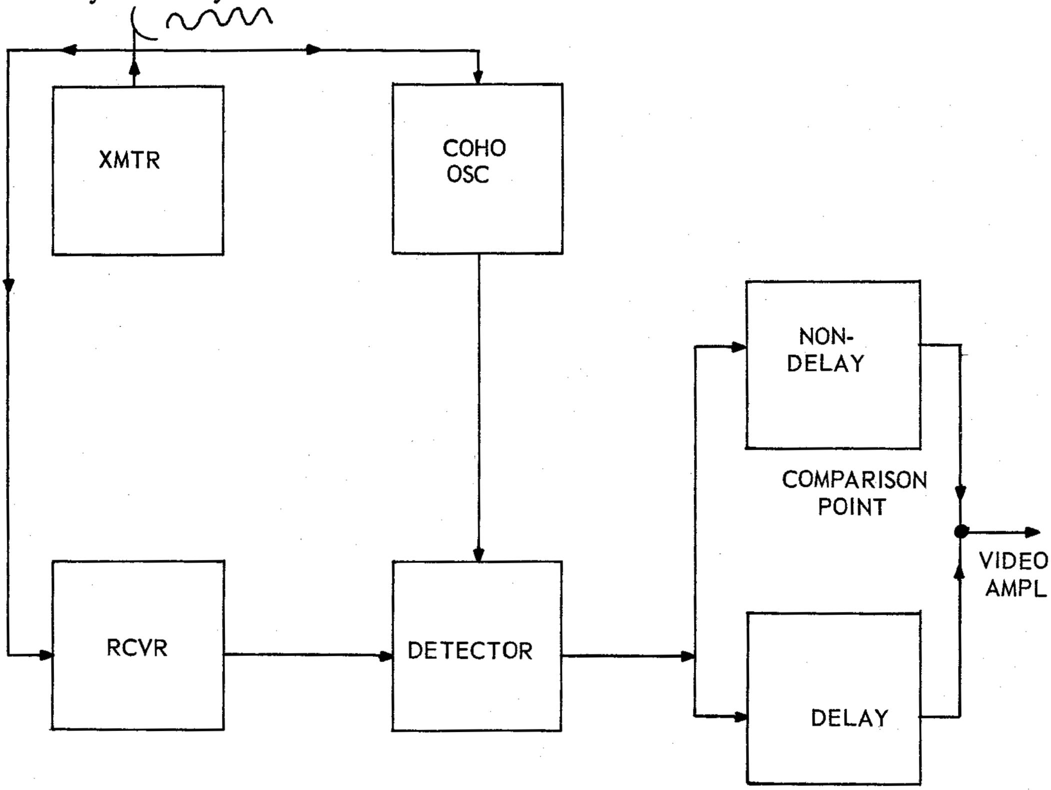

Figure 5. Block diagram of a basic MTI system.

b. Assuming that a target echo has been picked up by the radar receiver at 125 nautical miles, by calculation this will be about 1,500 microseconds in time from the radar site as shown in figure 6. The first target echo is received 1,500 microseconds after the

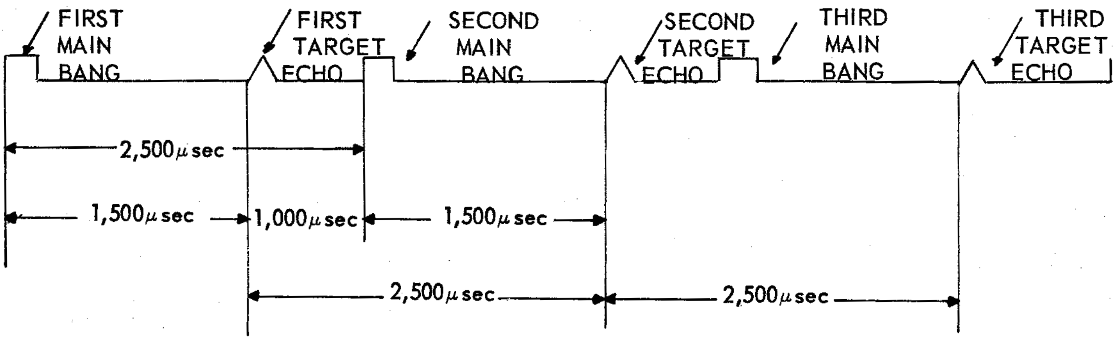

Figure 6. Time relationship of transmitted signals versus echo signals.

transmitter is fired for the first time. One thousand microseconds later the second transmitter pulse leaves the antenna and 1,500 microseconds later a second target echo is received. Since the time of reception of both of these target echoes is 1,500 microseconds in time after each transmitted pulse, it must be assumed that this is a fixed target echo.

c. When the first target echo is received and passes through the detector stage it is split, one part of the received pulse passing through the nondelay channel and the other part of the pulse passing through the delay channel. The return pulse passing through the nondelay channel appears at the comparison point immediately and is passed on to the video amplifiers. The return pulse applied to the delay channel requires 2,500 microseconds in time and is inverted before appearing at the comparison point. In the meantime, a second received target echo is passed through the nondelay channel and appears at the comparison point at the same time that the inverted output of the first pulse of the delay channel appears there. Assuming that both of these pulses (the first delayed target echo and the second nondelayed target echo) have the same shape, same amplitude, of opposite polarity, and occur at the comparison point at the same time, nothing will be passed on to the video amplifiers.

d. Assume now that the target has been moved a little closer to the radar between the first and second transmitter pulses as shown in figure 7. The first target echo appears

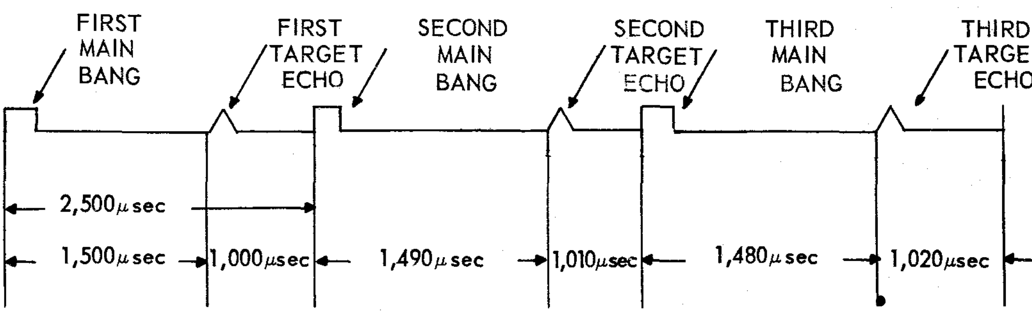

Figure 7. Time relationship of transmitted signals versus moving target echo signals.

at 125 nautical miles or approximately 1,500 microseconds in time. This target echo passes through the receiver and is split at the entrance to the nondelay and delay channels. The pulse passing through the nondelay channel appears at the comparison point immediately as it did with the fixed target echo. The pulse passing through the delay channel still requires 2,500 microseconds and is inverted before appearing at the comparison point. In the meantime, the transmitter fires a second time and again the antenna receives a target echo, but this target echo is only 115 nautical miles from the radar site or 1,490 microseconds in time. This second echo pulse is split after it leaves the detector and passes through the nondelay and delay channels. The output from the nondelay channel appears immediately at the comparison point or in this case only 2,490 microseconds after the first pulse appeared there. The portion of the pulse passing through the delay channel required 2,500 microseconds in time before it appeared inverted at the comparison point, or 10 microseconds later in time. Assuming that

these two pulses arrived at the comparison point with the same amplitude, of opposite polarity, with the same shape, but with a difference in time, video pulses will be passed on to the video amplifiers. Because of differences in time or phase of the output pulses of nondelay and delay channels, complete cancellation will not occur at the comparison point and a resultant output will pass to the video amplifiers.

e. The purpose of the coherent oscillator is to generate a reference signal phase-locked to a sample of the transmitter radar pulse. As shown in figure 5, a sample of the transmitter pulse is applied to the coherent oscillator each time the transmitter is fired, which results in the output of the coherent oscillator, which is applied to the detector, having the same phase as the transmitter pulses. Both the echo signal and the reference signal are applied to the detector, which responds to the phase difference between the two signals applied to it.

f. To have complete cancellation of fixed target echoes, certain requirements must be met as far as the output pulses at the comparison point are concerned. These requirements are:

(1) The pulses at the comparison point must have the same shape.

(2) The pulses at the comparison point must have the same amplitude.

(3) The pulses at the comparison point must be of opposite polarity.

(4) The pulses must arrive at the comparison point at the same time or phase relationship.

Section II. AN/TPS-1G GATED-MTI BLOCK DIAGRAM

5. GENERAL

a. In its principles of operation, radio set AN/TPS-1G is basically similar to most air-search radar systems. However, the inclusion of moving-target-indicator (MTI) requires some variations in circuitry as well as the addition of certain circuits peculiar to MTI (fig 8).

b. A magnetron oscillator, pulsed at 400 pps by a thyratron tube, generates the microwave transmitted energy. A thyratron trigger, generated by special timing circuits (including delay line networks), is used for both normal radar and MTI reception. An emergency trigger for normal radar use only is generated by the trigger generator on the modulator.

c. A reflector-type antenna is used to transmit the microwave energy and also to receive the energy reflected from objects. The antenna rotates to scan the surroundings, its bearing or azimuth information being relayed to the radar indicator by a synchro system.

d. An rf duplexing system, which includes dual cavities and two TR tubes, automatically switches the antenna between the transmitter and receiver. The received signals are converted from the microwave frequency (1,220 to 1,350 mc) to 60-mc through the use of

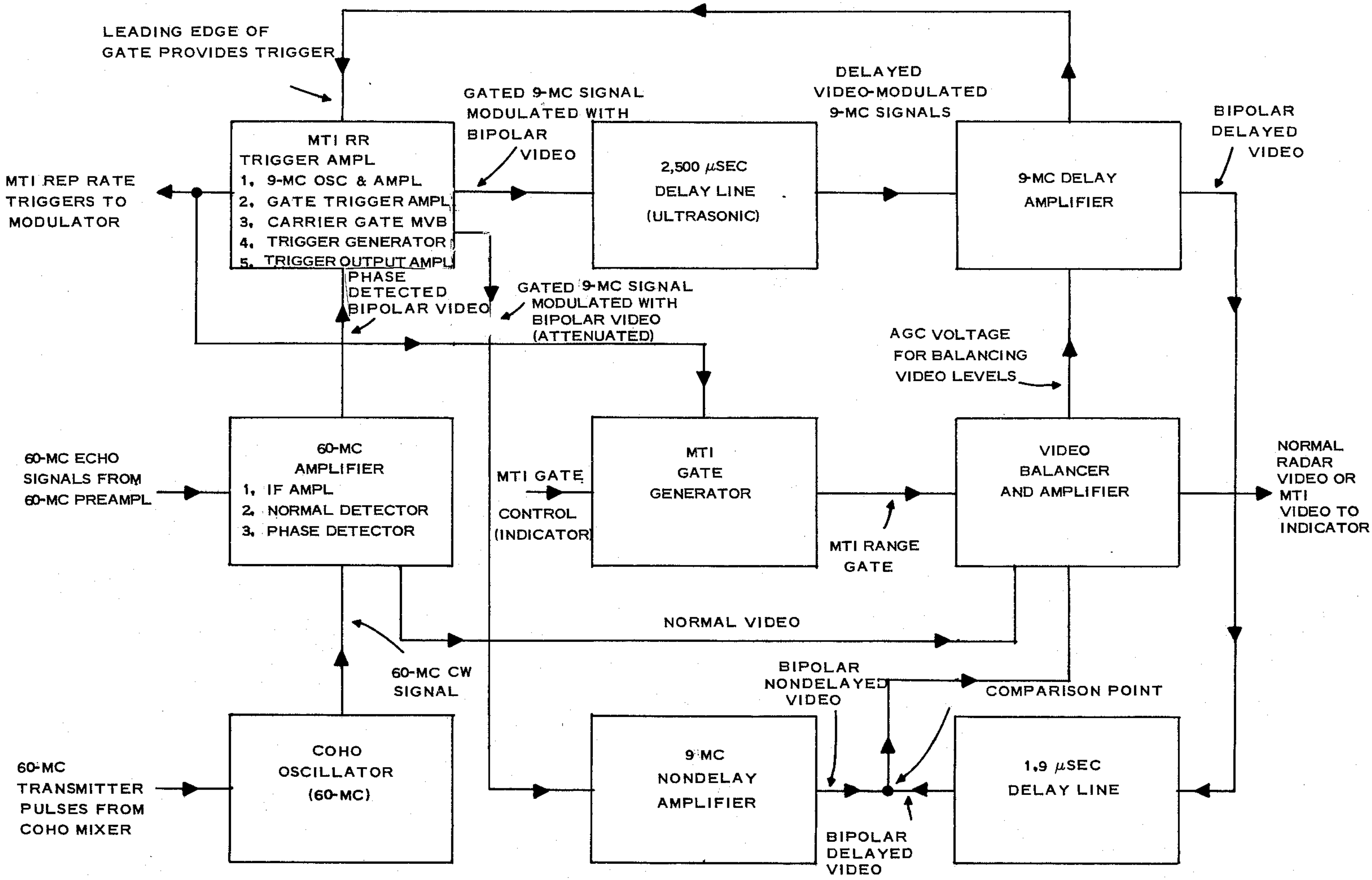

Figure 8. Block diagram of AN/TPS-1G gated-MTI system.

a grounded grid triode local oscillator and a crystal mixer. Signal voltages from the local oscillator also convert a minute portion of the transmitted signal to 60 mc through the use of an additional crystal mixer. This converted signal is used as a synchronizing signal in the signal comparator for MTI operation.

e. The signal needed for a normal radar display during either normal-radar or gated MTI operation is obtained from the amplified 60-mc signal in an amplitude-modulation detector, as in conventional radar practice.

f. The resultant video signal is then amplified, limited, and applied to both a PPI and an A-scope for display. The circuitry of the display tubes is conventional and includes the use of marker signals for obtaining range information. The range scales available (20, 40, 80, and 160 nautical miles) can be individually selected for either display. In addition. a 10-mile strobe sweep can be used in conjunction with the A-scope and is adjustable from 20 to 160 miles. The range at which the strobe is effective is indicated by a strobe marker signal on the PPI display.

g. In order to develop the MTI signals during gated-MTI operation, the MTI circuits handle the 60-mc received signals somewhat differently after amplification. Basically, an MTI system operates on the principle of comparing the rf phase difference between transmitted and received signals from one receiving period to the next. (A receiving period is the period between transmitted pulses.) Generally, signals from fixed objects have an unchanging phase difference, while signals from moving objects have a varying phase difference.

h. Phase detection is used at the output of the 60-mc amplifier to provide video signals for MTI. The phase detector produces video signals, the amplitude of which is a function of the phase difference between the received signals and a reference signal. The phase detector reference voltage is derived from a 60-mc cw coherent oscillator whose phase is locked to the rf phase of each transmitted pulse. Thus, phase comparison between transmitted and received signals is accomplished at the 60-mc phase detector.

i. The video signals developed by the phase detector are distributed to two channels, a delayed channel and an undelayed channel. The two circuits are such that the output signals of the delayed circuit are opposite in polarity and exactly one receiving period behind those of the undelayed circuit. The two signals are then combined.

j. If the signals are from fixed objects, the signal amplitudes will be the same from one receiving period to the next. Therefore, as the signals are of the same amplitude and timing and of opposite polarity, the signals will cancel when combined. However, if any of the signals are from objects which have motion, these signals will vary in amplitude from one receiving period to the next; and when these are combined a difference voltage will result. The difference voltage is then amplified, limited, and passed on to the display tubes.

k. Thus, during the MTI portion of a gated-MTI sweep, only moving targets are displayed. The MTI gating action is produced by an electronic switching circuit that routes either the normal radar signals or the MTI signals to the displays during their respective portions of each range sweep.

l. In order to establish precise coincidence between delayed and nondelayed signals, the delay circuits are also used to develop triggers for the thyratron modulators.

6. COHERENT OSCILLATOR CHANNEL

a. As the radar uses a reference phase MTI, it is necessary to have an oscillator that will represent the phase of the transmitter pulses. A reference phase MTI is commonly known as a coherent phase MTI; it uses a coherent oscillator to provide oscillations that continue from one transmission to the next. The oscillations are employed to gage the electrical distance to a target by use of a 60-mc signal.

b. At the time that the transmitter is pulsed, an attenuated 2-microsecond pulse is applied to the coherent mixer, which always has the local oscillator output being applied to it. Heterodying action takes place whenever both signals are applied, or for only 2 microseconds. The output of the coherent mixer is at a frequency of 60 megacycles. Since it is developed from the transmitted frequency, it represents the phase of the transmitted frequency at the beginning of each transmitter cycle.

c. The 2-microsecond, 60-mc sync pulse from the coherent mixer is applied as an input to the coherent oscillator channel. The pulse is amplified by three stages, V350, V351, and V352, and applied to the synchronized free-running, coherent oscillator V353. The oscillator is adjusted to operate at 60 mc and is synchronized in phase by the coherent mixer output. Once the 2-microsecond phasing action is completed, the free-running oscillations continue until the next transmitter cycle, when the synchronizing is repeated. The output from the oscillator is amplified in V354 and applied to the phase detector.

d. During the time that the coherent oscillator is free running, the transmitted energy is traveling through space from the antenna. If solid objects are in the path of the propagated energy, reflections return to the antenna and enter as 2-microsecond pulse returns into the signal mixer. The signal mixer, operating the same as in NORMAL operation, will have a 60-mc if output for every target return. The return echo is amplified by the 60-mc if amplifiers and applied to the phase detector along with the coherent oscillator output.

7. PHASE DETECTOR

a. The phase detector accomplishes the mixing and rectification of the 60-mc intermediate frequency and the 60-mc coherent oscillator signal. The detector converts phase differences into proportional amplitude changes.

b. The phase difference that is obtained for a moving target from one transmitter pulse to another is due to the time change that is necessary for the rf energy to travel to and from a moving target. There is no change of travel time in the case of a fixed target; therefore, there is no phase change at the phase detector. In referring to the phase change, it is not the rf energy wavefront that is changing in space but rather it is the action of the coherent oscillations in respect to the travel time of the returning echoes. The operation at the phase detector can best be understood by illustrations of the inputs to the detector. Multiple conditions may exist; figure 9 shows one possible condition.

c. When the transmitter pulses, the coherent oscillator is synchronized at T_o, figure 9(1). The oscillations continue and are applied to the phase detector. When signals return from the transmissions they are applied from the 60-mc if amplifiers into the phase detector. Figure 9(2) illustrates the returns from the first transmitter cycle. For explanation, assume that target A is moving and target B is fixed. After 2,500 microseconds, the transmitter cycle is again started and the same two target replies are received and channeled to the detector, figure 9(3). Notice that target A has shifted 45° in phase between transmissions because of an increase in the target's range during the 2,500-microsecond time. This phase shift is purely in reference to the coherent oscillator phase. However, the fixed target return, B, has not changed in phase with respect to the coherent oscillator signal, because its range is constant.

d. After the two 60-mc signals are mixed, the detection is accomplished by rectification either positively or negatively, depending upon the phase of the inputs. Figure 10 illustrates the amplitude and polarity of the video outputs for phase differences between detector inputs of from 0° to 360°. Because the phase difference is changing continuously for moving targets, the video output is changing in amplitude and polarity. Whereas, for any specific fixed target, the phase difference is always constant, the video output may be either positive or negative at a constant amplitude. Once the video polarity and amplitude are determined for a specific fixed target, that polarity and amplitude will not change.

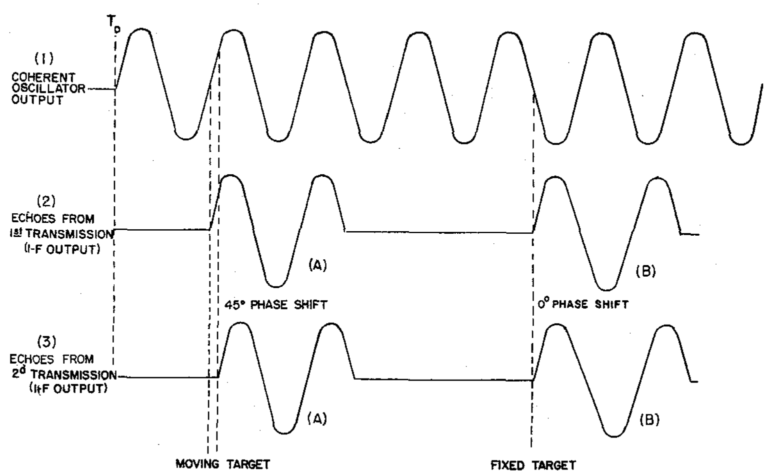

Figure 9. Phase detector action time.

e. For the detection of the signals in figure 9(3), target A and the coherent oscillator are in phase; i.e., there is a phase difference of 0°. Therefore, for that return, the video output of the detector is maximum negative. For target B, the two signals have an 180° phase difference and the video output will be a maximum positive. With the second transmission, target A has increased range and shifted in phase so that it has a 45° phase difference to the coherent oscillator. In this condition, the second output for that moving

target is negative in polarity and below maximum in amplitude. In return of target B for the second transmission, the phase difference remains at 180°; therefore, the same amplitude and polarity exist as for the first transmission.

f. The output of the detector for two successive transmitter pulses are shown in figure 10. If B and C are moving target returns, the amplitude and polarity of their video will change from one transmitter return to another. For target B, both the amplitude and polarity change between successive returns; however, for C there is only a decrease in amplitude. For the fixed target (A and D) video returns, the amplitude and polarity of the individual target video do not change. The bipolar video output from the phase detector is applied to the 0-mc oscillator for further processing.

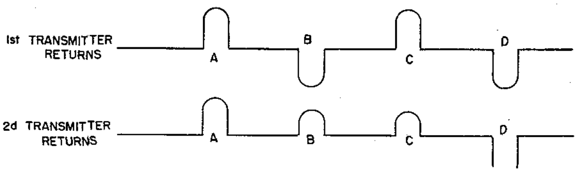

Figure 10. Video outputs from the phase detector for two trnasmissions.

8. MTI REPETITION RATE TRIGGER CIRCUITS

a. The positive and negative video pulses from the phase detector are applied to the 9-mc oscillator, V1355. The oscillator operates at 9 megacycles for a period of 2, 400 microseconds and is cut off for 100 microseconds, the oscillations acting as a carrier for the video signals. The oscillations are amplitude modulated by the positive and negative video pulses (fig 11). The purpose of the 9-mc oscillator is to convert the video from the phase detector into an amplitude modulated carrier with sufficient power to drive the delay line. The carrier, with its modulated signals, is amplified by V1356 and V1357 and applied to the delay and nondelay channels.

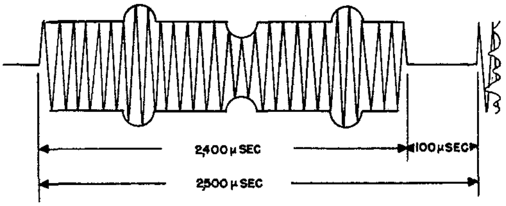

Figure 11. Output of the 9-mc oscillator.

b. The purpose of the timer is to accurately control the transmitter prf, so that fixed targets are cancelled at the comparison point. Since every video pulse is delayed 2, 500

microseconds and is compared with the identical target return from the following transmitter firing, the repetition time of the transmitter must be controlled by and be equal to the delay time in the signal comparator. The closed-loop circuits of the timer are shown in the block diagram (fig 12).

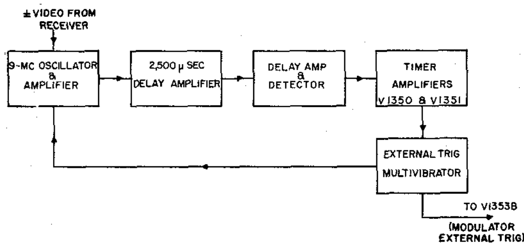

Figure 12. Block diagram of MTI repetition rate circuit.

c. The rectified output of delay detector V1306 is applied to the timing pulse amplifier, V1350, after differentiation (fig 13). The portion of the signal used to initiate the action of the timer circuits is at C. The negative input signals cause V1350 to be cut off and the plate voltage to rise, giving a positive output to the cutoff amplifier, V1351.

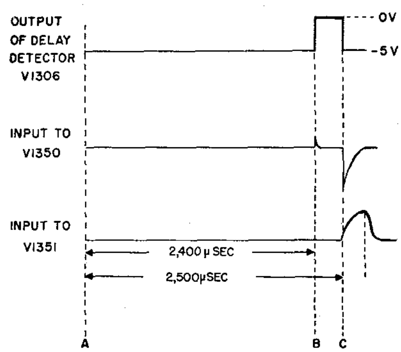

Figure 13. Delayed rectifier output and input to timer.

d. The sloping leading edge of the input signal to V1351 triggers the amplifier, depending upon the time balancing controls that may be varied from about 0 to 3 microseconds after the beginning of the input signal. This time balancing allows for fine timing for maximum cancellation at the comparison point.

e. A negative output pulse from V1351 is applied to a multivibrator, consisting of V1353A and V1354, which is the heart of the timer. The negative pulse cuts off V1354, and starts the next cycle of operation. When V1354 is cut off, the 9-mc oscillator starts oscillating and V1353A begins conducting with a negative output to V1353B.

f. The negative pulse is used to cut off V1353B, which contains a 50-kc tank circuit that oscillates when the stage is in cutoff. Upon oscillation the first output alternation goes negative, and the first positive oscillation is used to trigger the EXTERNAL trigger amplifier, V1352. This causes a delay of 10 microseconds in the external trigger with respect to the turning on of the 9-mc oscillator. The output of V1352 is applied to the modulator circuits and is used as the precision timing trigger for the transmitter. The complete action of the MTI repetition rate circuits enables the timing control of the transmitter to be available from the signal comparator, where the accuracy is demanded.

9. DELAY LINE

a. The delay channel is composed of a quartz delay line and delay amplifiers. The long delay (2,500 microseconds) and wide bandwidth (3 mc) of the delay line are obtained by making use of the relatively slow velocity of transmission of mechanical vibrations through solids. The ultrasonic delay line achieves its delay by converting electrical energy into mechanical energy and passing the mechanical vibrations through a solid medium such as fused quartz. The velocity of propagation of the mechanical vibrations in fused quartz is approximately 151,000 times slower than electrical energy through a wire. There is little or no distortion of the input signal in the conversion to mechanical energy and back to electrical energy. The delay time is 2,500 microseconds, plus or minus 10 microseconds; the acoustic bandwidth is 3 mc, and the attenuation is less than 60 db. (The attenuation of spurious signals is at least 30 db below the desired signal.)

b. The 9-mc input signal from the repetition rate amplifier is applied to an electrode bonded to a piezoelectric crystal. The crystal in turn is bonded to the fused quartz with a conducting material in between to serve as a ground. Through the piezoelectric effect the electrical signals are converted into acoustical energy (mechanical vibrations). The crystal is tightly bonded to the quartz and therefore sets up mechanical vibrations that travel through the quartz and arrive at the output transducer, which is exactly the same in construction as the input transducer. Here, however, the mechanical vibrations are converted back into electrical energy.

10. DELAY AMPLIFIERS

Delay amplifiers are used to amplify the signals attenuated by 60 db up to a usable amplitude. The delayed 9-mc modulated carrier is amplified by V1301 through V1305 and detected by V1306. The delay detector converts the amplitude modulated carrier into bipolar video signals, which are riding at a negative dc level.. The input and output signals of the delay amplifier channel are shown in figure 14. The video information from the delayed amplifier is completely below ground and riding at a negative dc reference. It is then applied to the comparison point at V3303.

11. NONDELAY AMPLIFIERS

a. At the same time that the input signals are applied to the quartz delay line identical signals are sent into the nondelay channel which consists of an attenuation network and nondelay amplifiers. The 9-mc signal to the nondelay amplifier is attenuated approximately 60 db, 10 db of the attenuation being in the output circuit of V1357 in the MTI

repetition rate trigger amplifier and 50 db being in the input circuit of V2301. This amount of attenuation represents the maximum loss possible in the quartz delay line, W2350, and also the attenuation of W2351, both of which are in the delayed signal circuit. Thus, the output levels of the two circuits are made approximately equal.

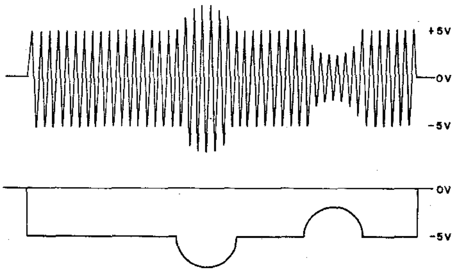

Figure 14. Input-output of the delay amplifier channel.

b. The attenuated signals are applied to the nondelay amplifiers, V2301 through V2305, for amplification. The same number of stages are used in the delay and nondelay amplifier channels for the proper shaping of the two signals. After sufficient amplitude is obtained in the nondelay amplifiers, the carrier is applied to the nondelay detector V2306. The detector converts the modulated carrier into bipolar video variations, and it is polarized to rectify the carrier at positive dc level, with the video impressed at that level. The input and output signals of the nondelay amplifier channel are shown in figure 15. The video information from the nondelay channel is applied to the comparison point at the input of V3303.

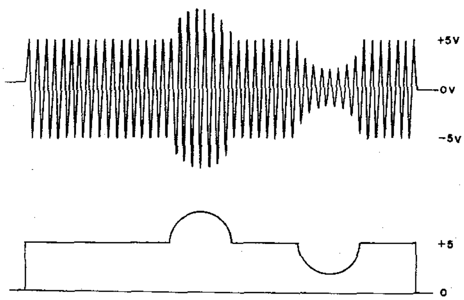

Figure 15. Input-output signals of the nondelay amplifier channel.

12. COMPARISON POINT

a. The nondelay and delay video signals appear at the comparison point (grid of V3303) where the fixed target returns are cancelled. At the time that a specific nondelay video pulse return is applied, another video pulse is appearing from the delay channel which has been delayed by 2,500 microseconds, the pulse repetition time of the transmitter. Therefore, all the echo returns from one transmission are compared with the echo returns from the previous transmission.

b. For complete cancellation of fixed targets, the following conditions must exist at the delay and nondelay detectors and at the comparison point. The video pulses must be:

(1) 180° out of phase.

(2) Of the same amplitude.

(3) Appearing at the same time.

(4) Of the same shape.

c. The method used to obtain the 180° out-of-phase condition for the nondelay and delay signals is accomplished by the detectors of the two channels. One detector is reversed in respect to the other; therefore, if a positive pulse is the output of the nondelay detector, the pulse representing the same target will be negative from the delay detector.

d. The amplitude of the nondelay video and the delay video is kept at the same value by an automatic bias circuit (V3300, V3301, and V3302) for the delay amplifiers. This will assure cancellation since both the video and the dc level from the delay and nondelay amplifiers are of opposite polarity. Any variation in the dc level on which the video is impressed tends toward failure of cancellation. The automatic bias control will either increase or decrease the negative dc level from the delay channel and cancellation will occur.

e. The nondelay and delay video signals must appear at the comparison point at the same time. However, the delay video pulses are delayed by 2,500 microseconds, the pulse repetition time of the transmitter. Actually, the time between transmission is determined by the total time delay of the delay channel; therefore, an assurance of time balance is obtained.

f. The shape of the video signals remains the same due to the equal number of stages in the delay and nondelay channels. In both channels, the signals are subject to the same distortion.

g. The output signals of the comparison point include only the moving target video, as the fixed target returns cancel. The cancellation of the fixed targets and change of moving target video are shown in figure 16. The moving target video output may be positive or negative and may be at various amplitude levels; it is applied to the video amplifiers.

13. VIDEO BALANCER AND AMPLIFIER

a. In this section of the signal comparator video signals from the delay and nondelay amplifiers are combined; and the difference signal voltage, if any, is amplified, limited, and fed to the indicator for MTI display. As MTI video input signals can be either positive or negative, a circuit is included that brings MTI video signals to one polarity. Separate video amplifiers are used for MTI and normal radar input signals, the amplifiers being arranged for video gating. Video output signals for remote indicator use are made available on a separate low-impedance circuit. The selection of either MTI or normal radar signals is accomplished by relay operation.

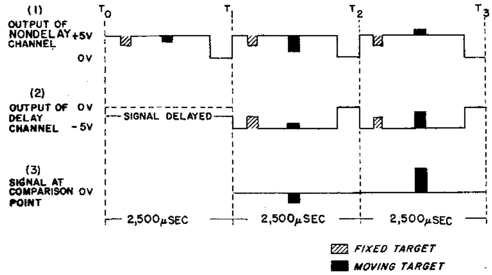

Figure 16. Video signals at comparison point.

b. Bias voltage for controlling the gain of the delay amplifier is also developed in this section of the signal comparator. It is by this means that the video levels of the delay and nondelay amplifiers are balanced.

c. The circuits of this section consist of MTI video combining amplifier V3303, phase inverter V3304 (including two rectifiers CR3300 and CR3301), MTI video limiter-amplifier V3305A, normal video limiter-amplifier V3305B, MTI gate V3306, normal video gate V3307, video amplifier V3311B, output cathode follower V3308 for indicator, and output cathode follower V3309 for repeater PPI. The bias for controlling the gain of the delay amplifier is developed by regulator tubes V3300 and V3302, and dc amplifier V3301.

d. The video signals, together with second-detector dc components, are fed to the grid of V3303 from the delay and nondelay amplifiers. As the dc components are at opposite polarity, they cancel at the grid of V3303 when the levels of the two circuits are in balance. If the dc levels are not equal, dc amplifier bias is developed to balance the dc levels of the two input signals. The two video signals are also of opposite polarity, and if they are of equal amplitude (as received from fixed targets) they cancel and no signal is applied to the grid of V3303. However, signals, as received from moving targets, generally have different video amplitudes, and therefore, the difference voltage is applied to the grid of V3303 (comparison point).

14. MTI GATE GENERATOR

a. In this section of the signal comparator are generated the gating pulses that key in the normal and MTI video, in their correct sequence, for gated-MTI operation.

b. The gate pulses are generated in the phantastron circuit of V3312. A controllable delay time is produced. Diode V3310A and its associated circuitry provide a means of controlling the pulse duration (in time and, consequently, in range) at which the system

switches from MTI to normal operation. The positive square wave output of the phantastron is taken off the screen grid and is directly coupled to the grid of phase splitter V3311A.

c. The outputs of V3311A are identical in amplitude and waveform but of opposite polarity. The cathode of V3311A is connected to the suppressor grid of the MTI gating stage V3307. Thus, the positive-going pulse keys in the MTI stage at the beginning of the receiving period while the normal stage is cut off. At a point determined by the control setting (in the circuitry of V3310A), the MTI stage is then cut off and the normal stage conducts. In the absence of gate pulses, V3307 conducts and V3306 is cut off.

15. SWITCHING

a. As would be necessary in a tactical situation, the radar may be operated in either GATED MTI or NORMAL. In GATED MTI, moving target returns and fixed target returns are displayed on the indicating screen; the range to which moving targets are displayed and fixed targets are cancelled is determined by the setting of MTI RANGE GATE control R603. In NORMAL operation, the indicator will display moving and fixed targets.

b. The OPERATION switch, located on the indicator panel, selects NORMAL or GATED MTI display. With the switch set GATED MTI, both MTI and normal video are applied to the indicator; MTI RANGE GATE control, on the indicator, sets range of MTI/NORMAL operation from 0 to 160 nautical miles. When the switch is set at NORMAL, only normal video (fixed and moving target returns) is applied to the indicator.

c. Located on the front panel of the indicator unit are the MTI AMPLITUDE BALANCE, MTI TIME BALANCE, and RECEIVER GAIN controls. These controls are switched into their respective circuits (through the contacts of relay K3301) when the OPERATION SELECTOR switch on the signal comparator is set at the REMOTE position. (At the same time, the same controls in the comparator are disconnected.)

Section III. SUMMARY AND QUESTIONS

16. SUMMARY

By having MTI operation, it is possible to cause the cancellation of fixed target returns and still have detection of moving targets. This cancellation is due to a precision pulse repetition period and the constant time that the rf energy must travel for a specific fixed target. The transmitter repetition period is controlled so that it equals the internal delay time that affects every target return.

17. QUESTIONS

a. What does MTI operation accomplish?

b. Briefly describe why fixed targets can be cancelled in MTI.

c. What is the purpose of the coherent oscillator?

d. What are the inputs and outputs of the phase detector?

e. What is the delay time of the delay channel? How does it compare with the transmitter repetition time?

f. What are the four requirements for signals to be cancelled at the comparison point?

g. How long is the 9-mc oscillator turned on? Off?

h. When V1354 is cut off, what is the status of the 9-mc oscillator?

CHAPTER 3

COHERENT OSCILLATOR AND PHASE DETECTOR

Section I. INTRODUCTION

18. GENERAL

As a target moves in respect to the radar antenna, the time that it takes for the rf energy to travel to and from the target changes accordingly. Since transmission occurs every 2,500 microseconds, the change of the target range is very small during that period. It is such a small change in range that very stable and accurate timing and measuring circuits must be used in order to cancel the fixed targets and detect the moving targets. This condition of accuracy must exist in gated MTI but it is not necessary in NORMAL operation, as all targets are observed on the screens. The indication of this small degree of target movement between transmissions is obtained by having a continuous reference signal in the form of 60-mc oscillations. This signal acts as a time base for making a comparison of all target returns. If the target moves from the time of one transmission to the next, the reply signal from that target is shifted along the time-base oscillations, so that different phases are obtained for each transmission. In the case of a fixed target where the range never changes, the reply signal cannot shift along the time base; therefore, the same phase exists for its replies from every transmission. The coherent oscillator provides the reference phase (time base) of 60 megacycles. The phase detector detects either a movement or a stationary condition in the target replies from successive transmissions.

Section II. THEORY OF OPERATION

19. MOVING TARGET DETECTION

a. In order to detect movement of targets various factors concerning the radar and target must be understood. Some of the initial factors are discussed below.

(1) The wavefront of the transmitted rf energy does not change in space but simply moves through space with the same wavefront reference as was propagated by the antenna.

(2) The local oscillator operates continuously and affects the phase of the 60-mc if signals and the first 2 microseconds of the coherent oscillator.

(3) The coherent oscillator is synchronized with the transmitter phase to represent its phase for each transmission. After being synchronized for 2 microseconds, the oscillator is free-running at 60 megacycles for each repetition period.

(4) The distance that the target travels during 2,500 microseconds determines the increase or decrease in the number of cycles that the local oscillator and coherent oscillator must provide, with respect to the previous

transmission. As a target increases in range, the cycles necessary to represent the range are increased over the previous transmission. If the target decreases in range, fewer cycles will be necessary.

b. To understand the above conditions, assume that an aircraft is flying an incoming course at 444 knots, or approximately 250 yards per second. Two succeeding transmitter pulses are used in order to see the detection of movement by a phase action. The range of the plane is 32, 800 yards, or 200 microseconds, at the time of the first transmission. The radar frequencies used are:

(1) Transmitter frequency is 1, 260 megacycles.

(2) Local oscillator frequency is 1, 320 megacycles.

(3) Coherent oscillator frequency is 60 megacycles.

(4) IF signal frequency is 60 megacycles.

Now, assume that the transmitter rf energy wavefront is 0° and the local oscillator at the same instant is 0°; however, the condition would seldom arise when the two frequencies would start at the same degree. From the following explanation, it can be seen that if either of the frequencies start at any phase other than 0°, the same change will be reflected proportionally at the point of the phase detection.

c. Computations for the above conditions can be made, but figure 17 illustrates the number of cycles necessary for target range. This graph shows the number of cycles of oscillation for the local oscillator and coherent oscillator during the period of time that it takes the rf energy to travel to the target and return.

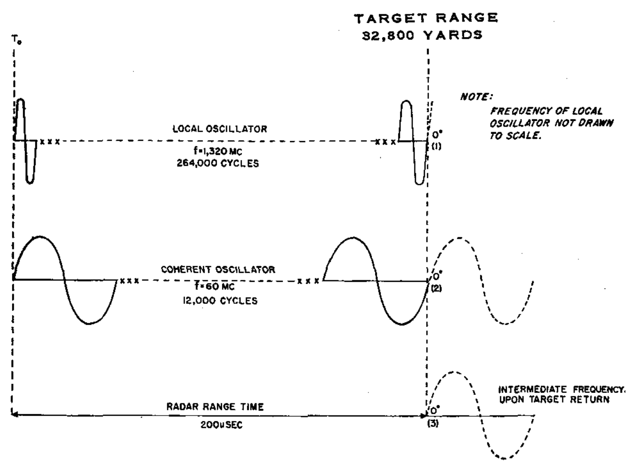

Figure 17. Operation of the receiving components during the 200-microsecond range.

d. The local oscillator oscillates through 264,000 cycles before the reflected signal is received; therefore, at the time of initial reception the wavefront is at 0° and the local oscillator is at 0° (fig 17(1)), so the 60-mc intermediate frequency will start at 0° (fig 17(3)). At the same time, the coherent oscillator has completed 12,000 cycles and represents 0° phase (fig 17(2)). Under this one target condition, it must be realized that the phase difference between the coherent oscillator and the if signal is 0°, and remains only for this one transmitter pulse return.

e. One transmission does not provide MTI; the next transmitted pulse data also must be considered. This occurs 2,500 microseconds after the first-pulse condition and during this time the target has increased in range by 0.625 yards, or a necessary range time of 200.00381 microseconds. During this increased time, the action of the receiving components is increased in time as shown in figure 17. Again, assume that the local oscillator and transmitter start from a 0° phase reference.

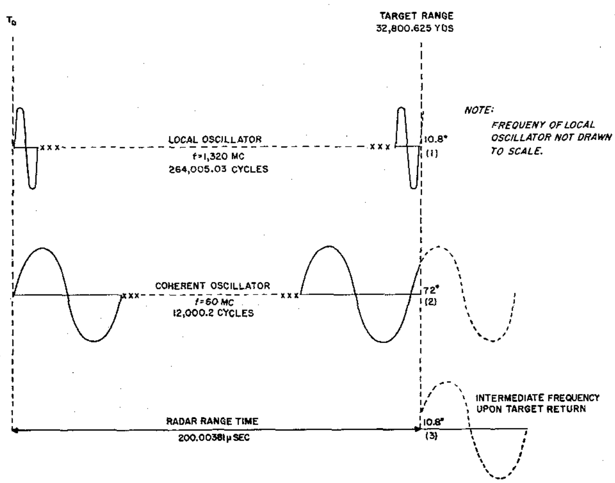

Figure 18. Operation of the receiving components during 200.00381 microseconds range.

f. The local oscillator has oscillated through 5.03 cycles more than for the previous transmission before it receives the target echo signal. However, in respect to the phase action, only the 0.03 of a cycle is the difference from the last comparison. With the 0.03 cycle, the local oscillator phase is 360° x 0.03 cycle, or a change of 10.8° (fig 18(1)). The intermediate frequency of the received signal represents 10.8° at the first instant of target reception (fig 18(3)). This change is compared to any change in the coherent oscillator, which has oscillated through an additional 0.2 cycles or 72° (fig 18(2)). Upon the reception of the first transmission, the phase difference was 0° between the if signal and the coherent oscillator; however, the second transmission reflects a difference between 10.8° and 72° which is equal to a difference of 61.2° in phase. This detection of phase change is the solution made available by coherent phase MTI systems.

g. If the target decreases in range, the resolution of movement is obtained in the same manner as for an increased range. The change of range, either increase or decrease, gives a resultant phase change in the return from one transmitter pulse to another.

h. The phase difference between the if and the coherent oscillator signals provides a resultant voltage pulse, with its polarity and amplitude depending upon the phase difference between the two signals. The phase difference between the signals and the polarity and amplitude of the resultant voltage pulse, or video, are shown in figure 19. For the first example discussed, the phase difference was 0°; therefore, the output would be one video pulse of maximum negative amplitude. The second return from the same target has a 61.8° phase difference so the output is still negative but much less in amplitude.

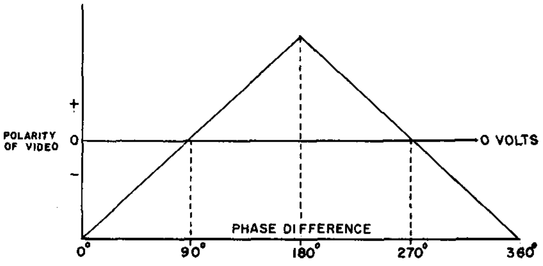

Figure 19. Video output from phase difference.

i. For a specific fixed target, it is readily seen that the range will never change, regardless of the number of transmissions. Therefore, the same phase always exists between the if and coherent oscillator signals and the video output from each target is always identical in amplitude and polarity. For the moving target, the video output is constantly changing in both amplitude and polarity.

20. GENERAL

a. The coherent oscillator and phase detector circuits enable the detection of phase differences in moving targets. The theory of operation that has been discussed must be understood in order to realize the need of the circuits contained in the two channels discussed below. The block diagram is shown in figure 20.

b. The coherent mixer, CR502, has two inputs applied to it at the time the transmitter is pulsed. The local oscillator output is always applied to the mixer at a frequency between 1, 280 and 1, 410 mc. When the transmitter is pulsed a 2-microsecond attenuated pulse from the rf system is applied to the mixer and it is at a transmitter frequency between 1, 220 to 1, 350 mc. When the two signals are heterodyned in the mixer, the resulting output frequency is 60 mc for a pulse width of 2 microseconds.

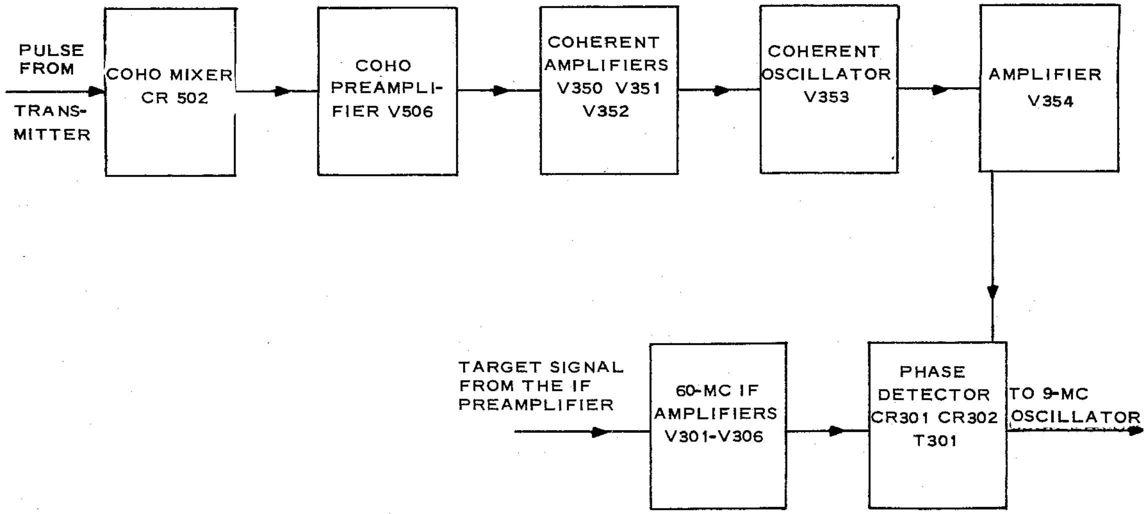

Figure 20. Block diagram of the coho oscillator and phase detector.

c. The output of the coho mixer is amplified by the coho preamplifier, V506. The amplifier provides a voltage amplification so that the signal will not be completely attenuated in the cabling from the receiver-transmitter to the signal comparator. The output of V506 is a 2-microsecond, 60-mc signal that represents the phase of the transmitter rf energy.

d. The 2-microsecond, 60-mc signal is amplified in the three stages of voltage amplifiers, V350 through V352. The output signal from V352 is applied to the coherent oscillator V353 and is of sufficient amplitude to provide a synchronization of the oscillator.

e. The oscillator is free-running at a tuned 60-mc frequency and the input signal from the coherent mixer is applied each time that the transmitter is pulsed. The sync signal represents the transmitted rf energy phase at a 60-mc frequency, and is impressed across the resonant circuit of the oscillator for a period of 2 microseconds, causing the oscillator to oscillate at its phase. The output of the oscillator is applied to amplifier V354, which applies its output into the phase detector.

f. The phase detector inputs are from the coherent oscillator channel and the if amplifier channel, with both signals at a frequency of 60 mc. The if amplifier has a 60-mc output to the detector only on reception of a target reply; however, the coherent oscillator output is always present at the detector. To have the correct output, the following conditions must exist:

(1) Both the if signal and coho oscillator signal must be present.

(2) The two signals must be of the same frequency and the same amplitude.

(3) The crystals, CR301 and CR302, must retain the same characteristics.

g. The output of the detector is either positive or negative video pulses, depending upon the phase difference between the two input signals. The bipolar video is then applied to the 9-mc oscillator channel.

Section III. DETAILED CIRCUIT ANALYSIS

21. COHO MIXER RF502. (fig 21)

The coho mixer tuned circuit consists of a short length of coaxial line having broadband characteristics. The line is fixed-tuned at midband and no tuning adjustments are required. The coho mixer crystal CR502 is connected into one end of the coaxial line, while the transmitter and local oscillator signals are capacity-coupled part way up the line. The local oscillator signal (set 60 mc higher in frequency than the magnetron) and the magnetron pulse signal beat to produce a 60-mc difference signal (pulse) at the output of the crystal mixer. This signal then goes to the coho preamplifier U502.

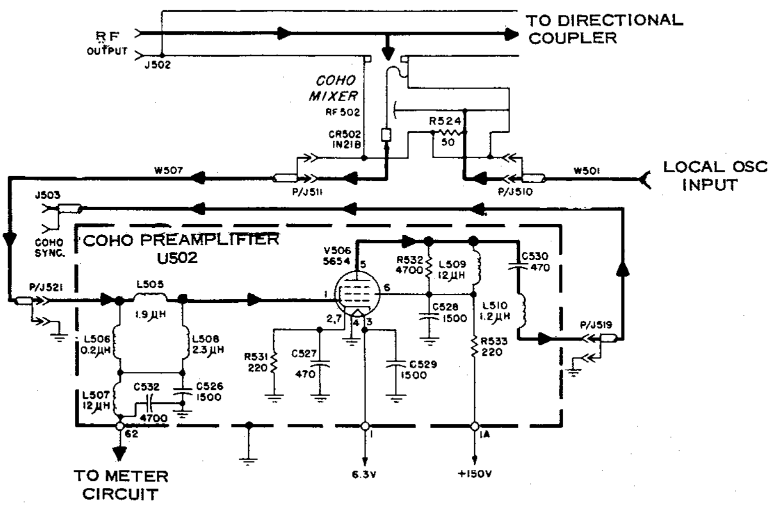

Figure 21. Coho mixer and coho preamplifier.

22. COHO PREAMPLIFIER U502. (fig 21)

a. This component amplifies the 60-mc pulses from the coho mixer. These pulses are the converted 2-microsecond pulses of the transmitter. The amplifier also provides isolation between the coho mixer and the output circuit. The output circuit supplies signals to the coherent oscillator in the signal comparator.

b. The amplifier is a single-stage amplifier consisting of V506 with fixed-tuned input and output circuits. The input circuit consists mainly of L505, L506, and L508. The circuit arrangement is the π equivalent of a double-tuned overcoupled circuit. This circuit provides the broadband (approximately 5 mc) characteristic required; and C526, C532, and L507 isolate the coho mixer crystal current (dc) circuit from the tuned circuit. Crystal current is passed from the C532 end of L507 to the metering circuit of M501.

c. The V506 plate and ouput circuit consists mainly of R532, L509, C530, L510, and the output circuit of J519. R532 is a damping resistor to provide a broadband output circuit. L509 is used for shunt feed of the dc plate voltage. C530 is a dc blocking capacitor and isolates the plate voltage from the output circuit. The plate circuit is tuned by the V506 output and circuit capacitances and by the inductance of L510 in series with the reactance of the output circuits. This circuit, often used as an input circuit, provides the necessary impedance transformation to couple the relatively high-impedance plate circuit to the low-impedance output circuit. Capacitor C528 acts both as the V506 screen bypass and as an RF grounding capacitor for R532 and L509. R533 is the V506 plate supply decoupling resistor.

23. COHERENT OSCILLATOR. (fig 22)

a. The coherent oscillator is a stable 60-mc oscillator whose phase is locked to the phase of each transmitted pulse. The coherent oscillator phase is therefore representative of the transmitter signal phase. The output of the oscillator is fed to the phase detector of the 60-mc if amplifier to provide a phase reference signal.

b. The oscillator consists of a 3-stage 60-mc amplifier (V350, V351, and V352), a 60-mc oscillator (V353), and an output amplifier (V354).

c. A small portion of the transmitter pulse signal, converted to 60 mc in the coho mixer, is amplified by the coho preamplifier, U502 (receiver-transmitter), and then further amplified by V350, V351, and V352. The amplified pulse signal is fed to the grid of V353, the equivalent of a grounded-plate oscillator having a high-C grid tank circuit-L354, C360, and C361.

d. The level of the 60-mc pulse signal is sufficient to phase-lock the 60-mc oscillator during the transmitter radiating period (2.0 microseconds). The oscillator has sufficient stability to maintain this phase during the receiving period (approximately 2, 500 microseconds). The COHO SYNC control R2355, permits setting the level of the 60-mc pulse signal from the coho preamplifier (receiver-transmitter) by adjusting the cathode bias of V350.

e. Condenser C361 is adjustable to permit setting the oscillator frequency to 60 mc. Negative resistance is obtained by the use of the cathode inductance, L355. The COHO LEVEL potentiometer, R2351, adjusts the voltage to the V353 screen (acting as the grounded plate of the oscillator), and hence sets the output level of the oscillator. One set of K3301 contacts opens the V353 screen supply to disable the oscillator for normal radar operation.

f. Oscillator output voltage is taken from the V353 plate circuit, which is electron-coupled to the oscillator circuit. The 60-mc phase-locked signal is then amplified by V354, which supplies 60-mc reference voltage to the phase detector circuit of the 60-mc if amplifier. Inductance L358, connected in the output circuit of V354, is used to tune out the capacitive reactance of the RG-62/U cable that carries the reference voltage to the 60-mc if amplifier phase detector.

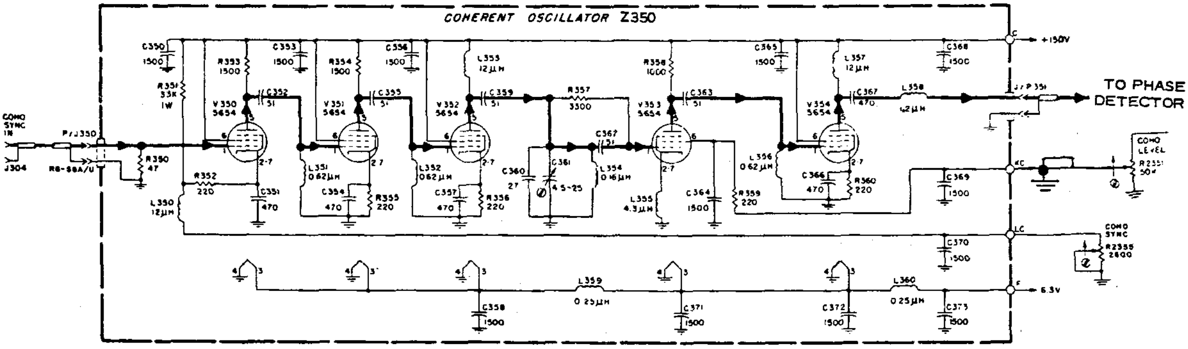

Figure 22. Coherent oscillator.

24. PHASE DETECTOR

a. The last if amplifier V306 is followed by two distinct types of detector circuits: one provides conventional amplitude-modulation (AM) detection of the echo signal for NORMAL radar display; the second provides phase detection of the echo signal for gated MTI display. The phase detector also provides, as by-products, two dc voltages for adjustment-checking in conjunction with internal test meter, M2350. One voltage indicates coho level, the other indicated if amplifier signal level. The low value of C375, between T302 and the grid of V308, is chosen so as to limit the signal level at the grid of V308 to that of the signal at V306. This assures the same signal level at the phase detectors, CR301 and CR302, as at the normal video detector, CR304.

b. In understanding the operation of the phase detector it should be noted in figure 23 that the coherent oscillator voltage is fed into the center of the secondary of T301 which carries received signal voltage. Thus, the coho voltage is fed to the two crystal rectifiers, CR301 and CR302, in series with the signal voltage induced into each half of the secondary of T301.

c. It should also be noted that CR301 and CR302 are poled in opposite directions, and also that R326, which forms part of the load resistance, is common to both sides of the output circuits of each rectifier. It is across this resistor (R326) that MTI video signal voltages are developed.

d. First consider a normal condition where coho voltage is present without the presence of received signal voltage. The voltages developed across the rf filter capacitors, C334 and C335, are equal and of opposite sign in relation to ground. Therefore, no signal voltage is developed across R326. This is also true for an abnormal MTI condition, where received signal voltage is present and coho voltage is absent. It can therefore be seen that no video signal is developed across R326 unless both signal voltages are present.

e. Now consider the situation where, with coho voltage present, a received signal voltage is induced in the secondary of T301, this voltage being in phase with the coho voltage. One half of the induced voltage across the secondary of T301 is added to the charge on one filter capacitor (C334 or C335), and a like voltage is subtracted from the other capacitor. The difference of these two voltages impressed on the capacitors then develops a voltage across R326 through R325 and R327. Initially the difference voltage is equal to the signal voltage but is reduced because of the voltage division of R325 and R326, and R327 and R326. The polarity of the voltage developed across R326 is of the same sign as that of the larger voltage with respect to ground. If the received signal voltage is shifted 180° in phase, the voltage developed across R326 is of the same amplitude but of opposite sign.

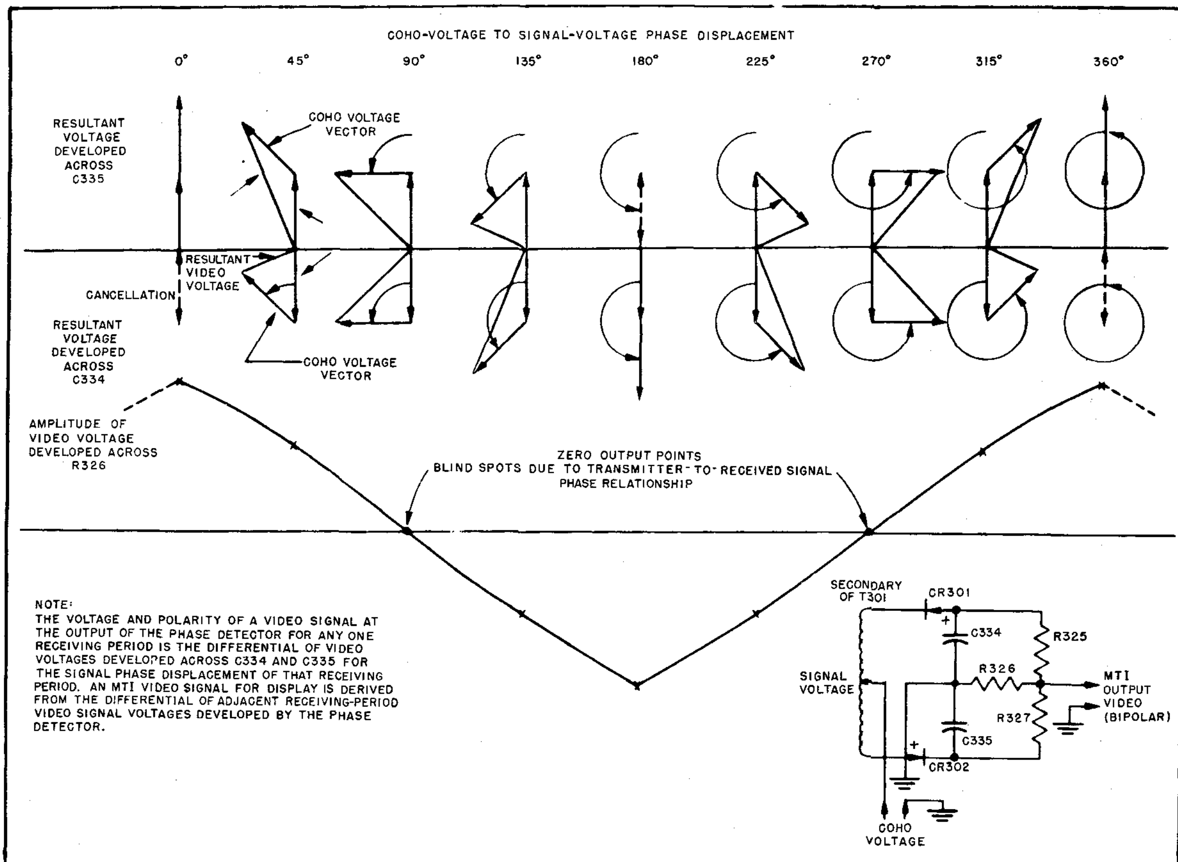

Figure 23. Phase detector characteristic.

f. For other received signal-to-coho-voltage phase displacements, the voltages developed across each half of the circuit are simply the peak voltages derived between the signal and coho voltages during the time each rectifier is conducting.

g. The coho oscillator voltage is adjusted by use of the test meter, described below, so that it is equal to the signal voltage across one half of the T301 secondary at limit level (approximately 4 volts). If the signal input phase is plotted against the coho phase, the phase detector characteristic of figure 23 is derived. The characteristic is plotted for equal signal voltages but holds reasonably true for all signal voltages up to limit level.

h. From this plot it can be seen that maximum phase detector output voltages appear at 0° and 180° phase displacement. Also, zero output voltage results at 90° and 270° phase displacement. Thus, the phase detector converts the 60-mc received signals to video signals of an amplitude and polarity dictated by the phase relationship of the received signals to the coho oscillator, two blind spots existing at 90° and 270°.

i. In studying the phase detector operation, the need for limiting received signals becomes more apparent. The output of the phase detector is dependent not only on the phase relationship of the two signals, but also on the voltage level of the received signal. Therefore, clutter signals, which normally have no phase difference from one receiving period to the next, can have period-to-period amplitude changes. And since amplitude changes can be passed on to the output of the phase detector, resulting in indications not only of moving target signals but also to some degree of clutter signals, limiting becomes a necessity.

j. The output of the phase detector is fed directly to the 9-mc oscillator in the MTI repetition rate trigger amplifier. When the radar is used as a normal system, the coho oscillator signal is removed and normal radar video signals are obtained from CR304 which demodulates the 60-mc signals into load resistor R336. The video signal (negative) is then fed to V3005B, in the video balancer and amplifier circuit, through the contacts of K3300 and K3301.

k. To adjust either the coho oscillator or the received signal voltage, the voltage developed across C334 is sampled. As the coho oscillator voltage is cw, it develops dc across C334. This voltage is supplied to TEST METER M2350 via TEST SELECTOR switch S2353. The metering circuit is isolated from the detector signal circuit by filter R2358, R2363. Received signal video voltage is amplified by V307, rectified and filtered by CR303-R331-C341, and then fed to the metering circuit. This voltage is the if amplifier signal level mentioned earlier. The signal level is adjusted by means of potentiometer R2350. This control permits adjustment of the bias on the first and third if stages and, consequently, adjusts the gain of these stages. Inductance L307, in the grid circuit of V307, isolates V307 from the detector output circuit.

CHAPTER 4

TIMING AND EXTERNAL TRIGGER CIRCUITS, 9-MC OSCILLATOR CIRCUITS, AND QUARTZ DELAY LINE

Section I. INTRODUCTION

28. GENERAL

a. For the MTI system to operate properly, it is absolutely necessary that the transmitter prf be very accurately controlled so that the pulse repetition period will be constant from pulse to pulse. This is accomplished in the timing circuit, which, if it is not operating properly, will make gated MTI operation impossible.

b. The 9-mc oscillator channel is employed to accept the bipolar video pulses from the phase detector output. These video pulses are then applied to the 9-mc carrier in the form of amplitude modulation. In connection with the choice of 9 mc as a carrier fequency, it should be mentioned that cancellation takes place after the carrier is rectified. Therefore, the carrier frequency must be high enough to insure a sufficient number of cycles to reproduce the carrier modulation envelope, including the video pulse rise time, with adequate accuracy of pulse shape reproduction for good cancellation. The amplitude of the carrier must be sufficient in power to compensate for the great attenuation of the quartz delay line.

c. The delay line acts as a memory circuit for all signal inputs into it. In operation, the line has applied all of the echo returns for one transmitter pulse and retains the echoes within the line for 2, 500 microseconds, or one pulse repetition time. In this manner, it is possible to have a comparison between echo returns from two successive transmissions.

Section II. THEORY OF OPERATION

29. GENERAL

a. The purpose of the timer is to accurately control the transmitter prf so that fixed targets can be canceled at the comparison point. If the prf is allowed to vary, even by a small amount, the pulse repetition period will vary. Since each pulse is delayed by 2, 500 microseconds and is compared with the following pulse, the transmitter firing must occur exactly 2, 500 microseconds later in order that the two pulses arrive in coincidence at the comparison point. Since the delay line, W2350, delays each signal 2, 500 microseconds, it follows that, if the delay line is incorporated in the feedback loop of the timer, then the prf is controlled so that the time between transmitter pulses would be 2, 500 microseconds or the delay of the delay channel.

b. Figure 24 shows how the delay channel is incorporated to accurately control the pulse repetition frequency. The heart of the timer circuit is a free-running multivibrator, V1351A and V1354, sometimes called the carrier gate multivibrator, which controls the operation of the 9-mc modulated oscillator (V1355) and the external trigger generator (V1353B). The multivibrator is adjusted to produce an asymmetric square wave as shown in figure 25 (1)

and (2). If the multivibrator were allowed to run at its natural frequency, the total period would be from T_o to T_n. The period from T_o to T_1 is adjusted for approximately 2, 400 microseconds, which means the 9-mc oscillator will run for that amount of time (fig 25(3)) and V1354 will be cut off during the same time.

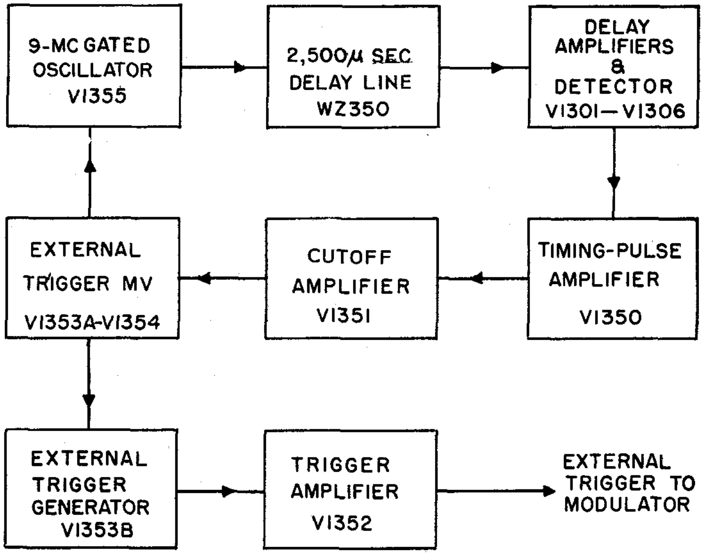

Figure 24. Block diagram of MTI repetition rate trigger amplifier.

c. The first portion of the 9-mc oscillations appears at the output of the delay line 2, 500 microseconds after the oscillator was started by the multivibrator. This output is amplified and detected by the delay amplifier (fig 25(4)) and is peaked and applied to the timing pulse amplifier, V1350 (fig 25(5)).

d. The timing-pulse amplifier, V1350, operates at zero bias; therefore it amplifies only the negative peak, and grid limits the positive peak. The output of the pulse amplifier is a positive pulse with a sloped leading edge (fig 25(6)).

e. The output of the timing pulse amplifier is applied to the cutoff amplifier, V1351 (fig 25(6)). The cutoff amplifier operates between $1\frac{1}{2}$ to 6 times cutoff, so that it produces no signal until the sloped leading edge of the input signal brings the grid out of cutoff. The output is a negative pulse that occurs approximately 2, 500 microseconds after the multivibrator has started. This negative pulse (fig 24(7)) is then applied to the grid of the conducting section of the multivibrator, V1354, cutting it off, and starting a second cycle of operation. Consequently, the multivibrator will not run at its natural period, T_o to T_n, but will be synchronized to run at a period from T_o to T_2, obtaining an accurate frequency.

f. To develop triggers for the modulator, the output from the V1353A section of the multivibrator (fig 25(2)) is applied to the grid of a 50-kc shock-excited oscillator (V1353B). The shock-excited ringing oscillator is cut off by the multivibrator, and produces damped oscillations which are fed to trigger amplifier V1352 (fig 25(8)).

g. Since the trigger amplifier, V1352, is operating near cutoff, the first negative alternation of the damped oscillations is not amplified. However, the positive alternation causes the tube to conduct hard, producing a negative pulse at the plate (fig 25(9)). This negative pulse is the external trigger and is sent to the modulator trigger channel. Since the trigger amplifier did not amplify the first negative alternation, there is a small delay introduced between the starting of the 9-mc oscillator (V1355) and the production of the external trigger

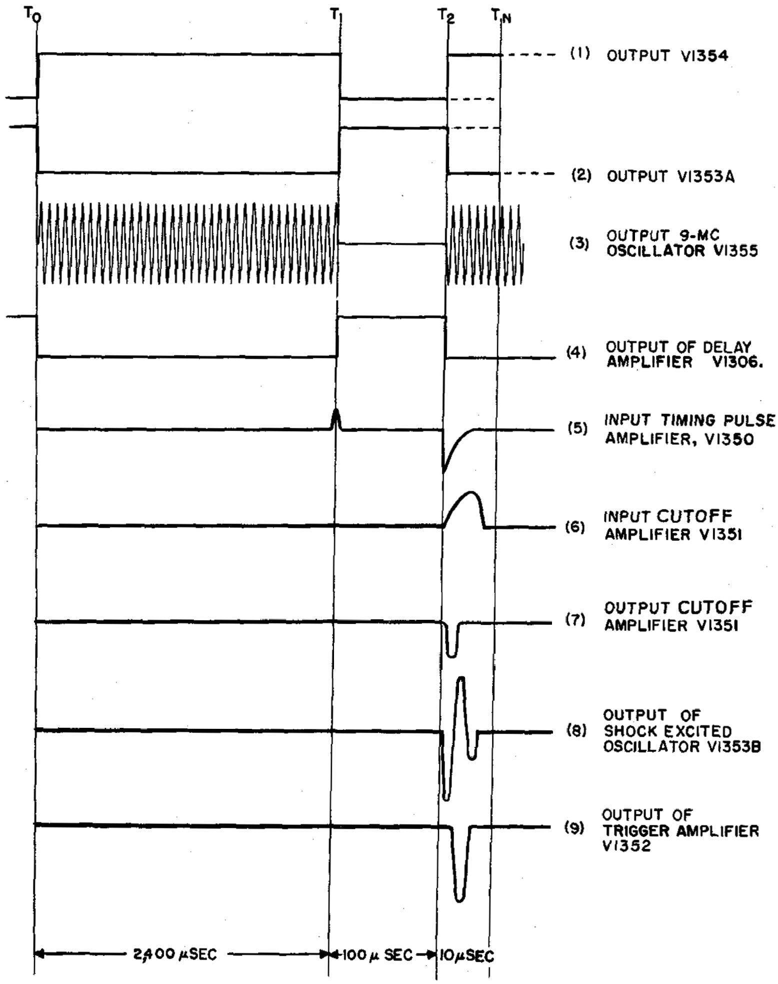

Figure 25. Waveforms in the timer.

This delay of 10 microseconds, which is equal to the period of the negative alternation, is necessary to allow the oscillator to start before the transmitter is fired by the external trigger. The actual purpose of this small delay will be discussed later in more detail.

h. The positive and negative output video pulses from the phase detector are applied to the 9-mc oscillator, V1355. The oscillator operates for 2, 400 microseconds at a frequency of 9 mc and is cut off for 100 microseconds, and the sum of the two periods is the time between the transmitter pulses. The oscillator starts operation 10 microseconds before the transmitter is pulsed, allowing time for the delay line to reach stable operation before the modulated signals are applied. These time relations are shown in figure 26. Due to the power required to drive the quartz delay line, it is more efficient to use a carrier that is amplitude modulated by the video pulses, rather than using power amplified video as the driving source.

i. The amplitude modulated carrier is applied to a voltage amplifier, V1356, followed by a power amplifier, V1357. The amplifiers build the signal to sufficient power necessary to excite the input crystal at the quartz delay line.

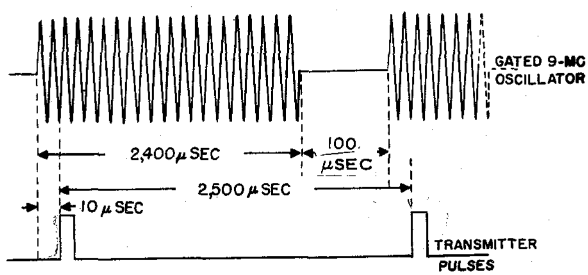

Figure 26. Time relation of transmitter and 9-mc oscillator.

j. The signal from V1357 is divided into three channels in the output network. The three outputs are applied to the attenuation network and nondelay channel, 2, 500-microsecond delay line W2350, and TEST METER M2350.

k. The long delay (2, 500 microseconds) and wide bandwidth (3 mc) of the delay line are obtained by making use of the relatively slow velocity of transmission of mechanical vibrations through solids. The ultrasonic delay line achieves its delay by converting electrical energy into acoustical energy (mechanical vibrations) and passing the vibrations through a solid medium such as fused quartz. The velocity of propagation of acoustical energy in fused quartz is approximately 151, 000 times slower than electrical energy through a wire.

l. The 9-mc input signal from the repetition rate amplifier is applied to an electrode that is bonded to a piezoelectric crystal. The crystal in turn is bonded to the fused quartz with a conducting material in between to serve as a ground. Through the piezoelectric effect, the electrical signals are converted into acoustical energy (mechanical vibrations). The crystal is tightly bonded to the quartz and therefore sets up mechanical vibrations that travel through the quartz and arrive at the output transducer, which is exactly the same in construction as the input transducer. Here, however, the mechanical vibrations are converted back into electrical energy.